QUICK LAB

Bend a Wall

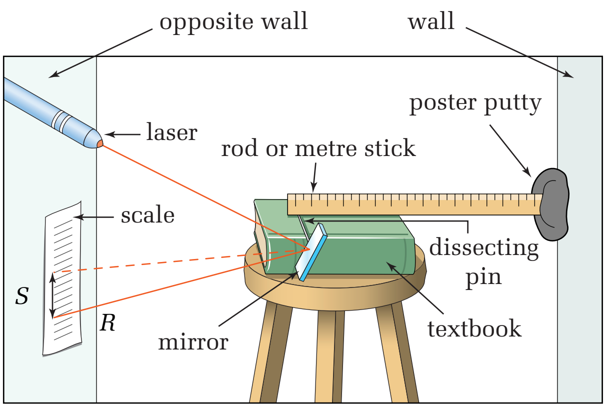
TARGET SKILLS

- Initiating and planning
- Performing and recording
- Analyzing and interpreting

Sometimes it might not seem as though an object on which you are pushing is exhibiting any type of motion. However, the proper apparatus might detect some motion. Prove that you can move — or at least, bend — a wall.

CAUTION Do not look into the laser.

Glue a small mirror to a 5 cm T-head dissecting pin. Put a textbook on a stool beside the wall that you will attempt to bend. Place the pin-mirror assembly on the edge of the textbook. As shown in the diagram, attach a metre stick to the wall with putty or modelling clay and rest the other end on the pin-mirror assembly. The pin-mirror should act as a roller, so that any movement of the metre stick turns the mirror slightly. Place a laser pointer so that its beam reflects off the mirror and onto the opposite wall. Prepare a linear scale on a sheet of paper and fasten it to the opposite wall, so that you can make the required measurements.



Push hard on the wall near the metre stick and observe the deflection of the laser spot. Measure

- the radius of the pin (r)
- the deflection of the laser spot (S)
- the distance from the mirror to the opposite wall (R)

Analyze and Conclude

1. Calculate the extent of the movement (s) — or how much the wall "bent" — using the formula $s = \frac{rS}{2R}$.
2. If other surfaces behave as the wall does, list other situations in which an apparently inflexible surface or object is probably moving slightly to generate a resisting or supporting force.
3. Do your observations "prove" that the wall bent? Suppose a literal-minded observer questioned your results by claiming that you did not actually see the wall bend, but that you actually observed movement of the laser spot. How would you counter this objection?
4. Is it scientifically acceptable to use a mathematical formula, such as the one above, without having derived or proved it? Justify your response.
5. If you have studied the arc length formula in mathematics, try to derive the formula above. (Hint: Use the fact that the angular displacement of the laser beam is actually twice the angular displacement of the mirror.)

Apply and Extend

6. Imagine that you are explaining this experiment to a friend who has not yet taken a physics course. You tell your friend that "When I pushed on the wall, the wall pushed back on me." Your friend says, "That's silly. Walls don't push on people." Use the laws of physics to justify your original statement.
7. Why is it logical to expect that a wall will move when you push on it?
8. Dentists sometimes check the health of your teeth and gums by measuring tooth mobility. Design an apparatus that could be used to measure tooth mobility.

Frames of Reference

In order to use Newton's laws to analyze and predict the motion of an object, you need a reference point and definitions of distance and direction. In other words, you need a **coordinate system.** One of the most commonly used systems is the Cartesian coordinate system, which has an origin and three mutually perpendicular axes to define direction.

Once you have chosen a coordinate system, you must decide where to place it. For example, imagine that you were studying the motion of objects inside a car. You might begin by gluing metre sticks to the inside of the vehicle so you could precisely express the positions of passengers and objects relative to an origin. You might choose the centre of the rearview mirror as the origin and then you could locate any object by finding its height above or below the origin, its distance left or right of the origin, and its position in front of or behind the origin. The metre sticks would define a coordinate system for measurements within the car, as shown in Figure 1.2. The car itself could be called the **frame of reference** for the measurements. Coordinate systems are always attached to or located on a frame of reference.

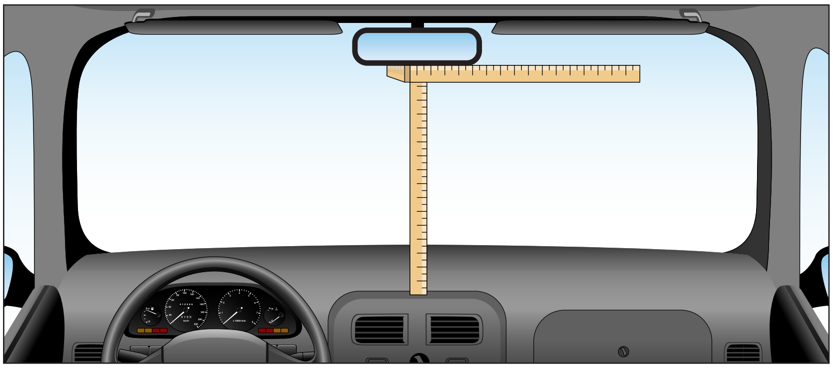


Figure 1.2 Establishing a coordinate system and defining a frame of reference are fundamental steps in motion experiments.

An observer in the car's frame of reference might describe the motion of a person in the car by stating that "The passenger did not move during the entire trip." An observer who chose Earth's surface as a frame of reference, however, would describe the passenger's motion quite differently: "During the trip, the passenger moved 12.86 km." Clearly, descriptions of motion depend very much on the chosen frame of reference. Is there a right or wrong way to choose a frame of reference?

The answer to the above question is no, there is no right or wrong choice for a frame of reference. However, some frames of reference make calculations and predictions much easier than do others. Think again about the coordinate system in the car. Imagine that you are riding along a straight, smooth road at a constant velocity. You are almost unaware of any motion. Then

COURSE CHALLENGE

Reference Frames

A desire to know your location on Earth has made GPS receivers very popular. Discussion about location requires the use of frames of reference concepts. Ideas about frames of reference and your *Course Challenge* are cued on page 603 of this text.

PHYSICS FILE

Albert Einstein used the equivalence of inertial and gravitational mass as a foundation of his general theory of relativity, published in 1916. According to Einstein's principle of equivalence, if you were in a laboratory from which you could not see outside, you could not make any measurements that would indicate whether the laboratory (your frame of reference) was stationary on Earth's surface or in space and accelerating at a value that was locally equal to *g*.

the driver suddenly slams on the brakes and your upper body falls forward until the seat belt stops you. In the frame of reference of the car, you were initially at rest and then suddenly began to accelerate.

According to Newton's first law, a force is necessary to cause a mass — your body — to accelerate. However, in this situation you cannot attribute your acceleration to any observable force: No object has exerted a force on you. The seat belt stopped your motion relative to the car, but what started your motion? It would appear that your motion relative to the car did not conform to Newton's laws.

The two stages of motion during the ride in a car — moving with a constant velocity or accelerating — illustrate two classes of frames of reference. A frame of reference that is at rest or moving at a constant velocity is called an **inertial frame of reference**.

When you are riding in a car that is moving at a constant velocity, motion inside the car seems similar to motion inside a parked car or even in a room in a building. In fact, imagine that you are in a laboratory inside a truck's semitrailer and you cannot see what is happening outside. If the truck and trailer ran perfectly smoothly, preventing you from feeling any bumps or vibrations, there are no experiments that you could conduct that would allow you to determine whether the truck and trailer were at rest or moving at a constant velocity. The law of inertia and Newton's second and third laws apply in exactly the same way in all inertial frames of reference.

Now think about the point at which the driver of the car abruptly applied the brakes and the car began to slow. The velocity was changing, so the car was accelerating. An accelerating frame of reference is called a **non-inertial frame of reference**. Newton's laws of motion do *not* apply to a non-inertial frame of reference. By observing the motion of the car and its occupant from outside the car (that is, from an inertial frame of reference, as shown in Figure 1.3), you can see why the law of inertia cannot apply.

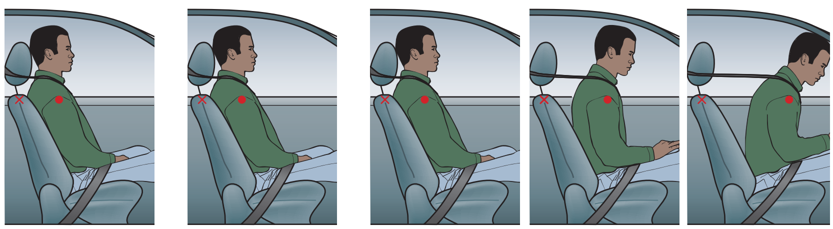


Figure 1.3 The crosses on the car seat and the dots on the passenger's shoulder represent the changing locations of the car and the passenger at equal time intervals. In the first three frames, the distances are equal, indicating that the car and passenger are moving at the same velocity. In the last two frames, the crosses are closer together, indicating that the car is slowing. The passenger, however, continues to move at the same velocity until stopped by a seat belt.

In the first three frames, the passenger's body and the car are moving at the same velocity, as shown by the cross on the car seat and the dot on the passenger's shoulder. When the car first begins to slow, no force has yet acted on the passenger. Therefore, his

body continues to move with the same constant velocity until a force, such as a seat belt, acts on him. When you are a passenger, you feel as though you are being thrown forward. In reality, the car has slowed down but, due to its own inertia, your body tries to continue to move with a constant velocity.

Since a change in direction is also an acceleration, the same situation occurs when a car turns. You feel as though you are being pushed to the side, but in reality, your body is attempting to continue in a straight line, while the car is changing its direction.

INERTIAL AND NON-INERTIAL FRAMES OF REFERENCE

An inertial frame of reference is one in which Newton's first and second laws are valid. Inertial frames of reference are at rest or in uniform motion, but they are not accelerating.

A non-inertial frame of reference is one in which Newton's first and second laws are not valid. Accelerating frames of reference are always non-inertial.

Clearly, in most cases, it is easier to work in an inertial frame of reference so that you can use Newton's laws of motion. However, if a physicist chooses to work in a non-inertial frame of reference and still apply Newton's laws of motion, it is necessary to invoke hypothetical quantities that are often called **fictitious forces:** inertial effects that are perceived as "forces" in non-inertial frames of reference, but do not exist in inertial frames of reference.

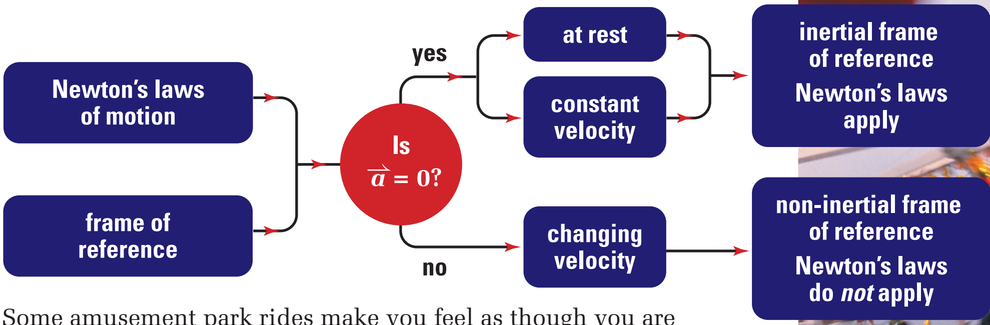
Conceptual Problem

- Passengers in a high-speed elevator feel as though they are being pressed heavily against the floor when the elevator starts moving up. After the elevator reaches its maximum speed, the feeling disappears.
  - **(a)** When do the elevator and passengers form an inertial frame of reference? A non-inertial frame of reference?
  - **(b)** Before the elevator starts moving, what forces are acting on the passengers? How large is the external (unbalanced) force? How do you know?
  - **(c)** Is a person standing outside the elevator in an inertial or non-inertial frame of reference?
  - **(d)** Suggest the cause of the pressure the passengers feel when the elevator starts to move upward. Sketch a free-body diagram to illustrate your answer.
  - **(e)** Is the pressure that the passengers feel in part (d) a fictitious force? Justify your answer.

PHYSICS FILE

Earth and everything on it are in continual circular motion. Earth is rotating on its axis, travelling around the Sun and circling the centre of the galaxy along with the rest of the solar system. The direction of motion is constantly changing, which means the motion is accelerated. Earth is a non-inertial frame of reference, and large-scale phenomena such as atmospheric circulation are greatly affected by Earth's continual acceleration. In laboratory experiments with moving objects, however, the effects of Earth's rotation are usually not detectable.

Concept Organizer



Some amusement park rides make you feel as though you are being thrown to the side, although no force is pushing you outward from the centre. Your frame of reference is moving rapidly along a curved path and therefore it is accelerating. You are in a non-inertial frame of reference, so it seems as though your motion is not following Newton's laws of motion.

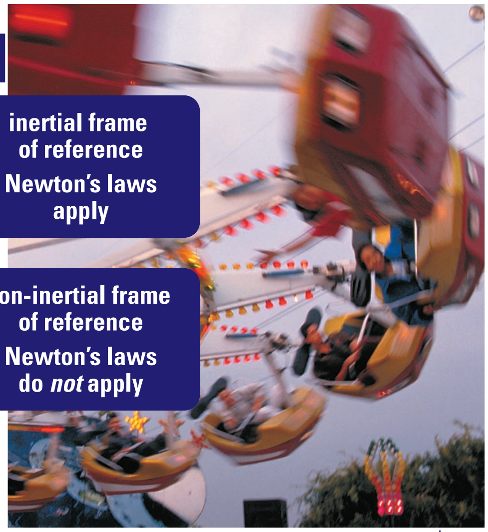


Figure 1.4 You can determine the nature of a frame of reference by analyzing its acceleration.

1.1 Section Review

1. **K/U** State Newton's first law in two different ways.
2. **C** Identify the two basic situations that Newton's first law describes and explain how one statement can cover both situations.
3. **K/U** State Newton's second law in words and symbols.
4. **MC** A stage trick involves covering a table with a smooth cloth and then placing dinnerware on the cloth. When the cloth is suddenly pulled horizontally, the dishes "magically" stay in position and drop onto the table.
   - **(a)** Identify all forces acting on the dishes during the trick.
   - **(b)** Explain how inertia and frictional forces are involved in the trick.
5. **K/U** Give an example of an unusual frame of reference used in a movie or a television program. Suggest why this viewpoint was chosen.
6. **K/U** Identify the defining characteristic of inertial and non-inertial frames of reference. Give an example of each type of frame of reference.
7. **C** In what circumstances is it necessary to invoke ficticious forces in order to explain motion? Why is this term appropriate to describe these forces?
8. **C** Compare inertial mass and gravitational mass, giving similarities and differences.
9. **C** Why do physicists, who take pride in precise, unambiguous terminology, usually speak just of "mass," rather than distinguishing between inertial and gravitational mass?

UNIT PROJECT PREP

- What frame of reference would be the best choice for measuring and analyzing the performance of your catapult?
- What forces will be acting on the payload of your catapult when it is being accelerated? When it is flying through the air?
- How will the inertia of the payload affect its behaviour? How will the mass of the payload affect its behaviour?

Test your ideas using a simple elastic band or slingshot.

CAUTION Take appropriate safety precautions before any tests. Use eye protection.